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Microwave Directional Coupler with high Front-to-Back Ratio made from Semi-Rigid Circuits

It is already one of the truisms heard at amateur radio tests that directional couplers can be used to measure the matching of aerials or other consumers. In their inevitable attempts to dismantle the mysterious boxes, mainly of Japanese or American manufacture, those seeking enlightenment encounter a structure made of sheet metal and wire, the mysterious working mechanism of which remains obscure, even after lengthy meditation in the wilderness.

Upon recognising, for instance, that current is flowing at one end of the strapping and not at the other, even a hard-bitten natural researcher of the stamp of a Georg Simon Ohm would drop the voltmeter in despair.

In spite of the apparent simplicity of the mechanism, home-made units are usually only partially successful. At any

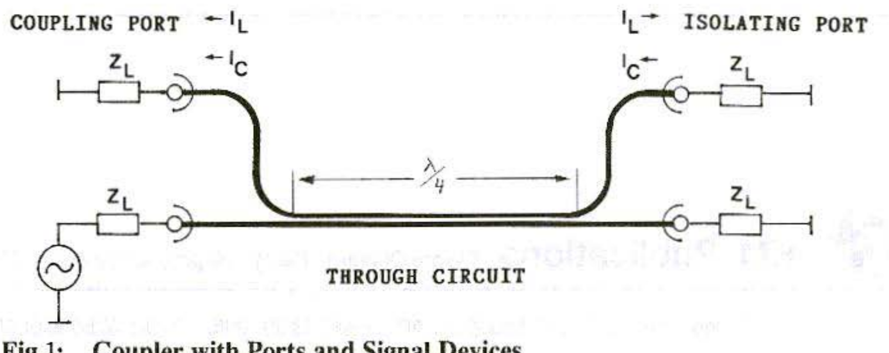


Fig.1: Coupler with Ports and Signal Devices

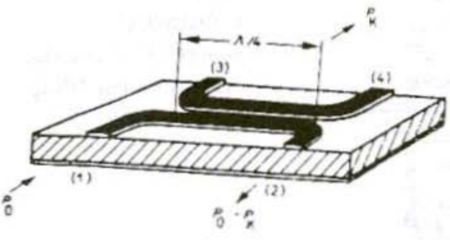


Fig.2: **Printed Directional Coupler on the basis of strip-lines.**

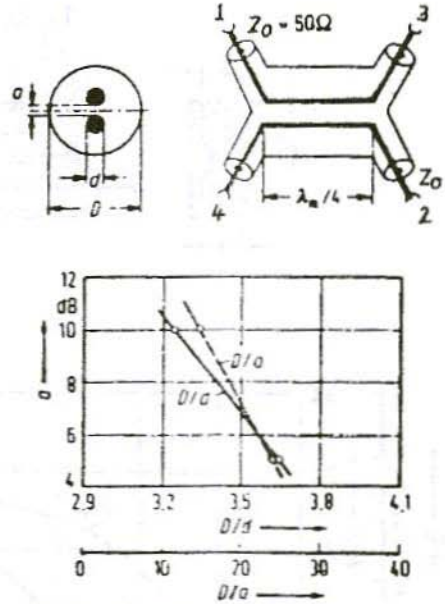


Fig.3: **Coupling Attenuations of so-called wire-lines**

rate, the longed-for high accuracy of alignment (the difference between the forward motion and backward motion lines) is not present. In the GHz range at any rate, only a few daring radio hams have succeeded in using lathes to create structures of a quality which could be paraded before a knowledgeable visitor.

It is the purpose of this article to present a mechanically simple, but electrically high-quality home-made solution, based on fixed sheath cables.

1. WORKING MECHANISM

The essential mystery of a directional coupler lies in the correct impedance of the main line and secondary line, together with the correct joining of these lines regardless of impedance.

A directional coupler is a kind of repeater in which, in contrast to the transformer, in addition to the magnetic coupling, a capacitive coupling of the same value exists between the main line and the secondary line. If all main line and secondary line impedances coincide (50 ohms is the usual value), then at one end of the secondary line the capacitive and the inductive coupling currents are of equal size and of the same phase, and thus reinforce each other. At the other end of the so-called secondary line, the phase angle between the two partial currents is 180 degrees, and they thus cancel each other out. Here a signal is transmitted only if a wave is flowing along the main line in the opposite direction, i.e: if a standing wave is present as a result of mismatching by the user (Fig.1).

Such strong directional relationships can be obtained only if a high degree of symmetry exists between the two wave components (referred to more simply as currents) due to the maintenance of the impedances. Thus, for example, for an accuracy of alignment of only 20dB, the power delivered at the uncoupled end of the secondary line has to constitute only

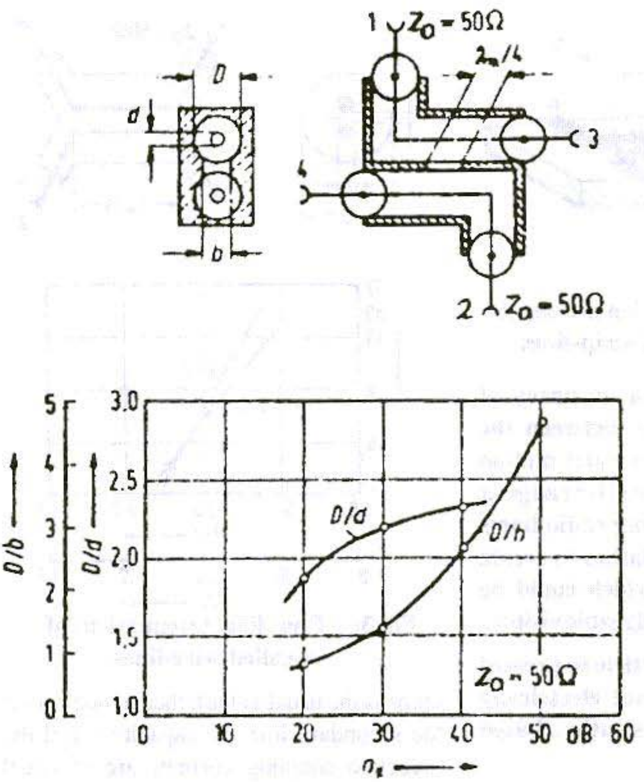


Fig.4: Influence of geometry of coaxial system on coupling attenuations

one per cent of that at the other end. Mismatching, even of the terminal resistance (wave sump) of the secondary line results in internal reflections, which lead to standing waves within the coupler and also impair the accuracy of alignment.

Home-made units constructed using sheet metal techniques usually require considerable mechanical engineering resources and industrial products from the high-tech range have to be purchased new with no price discounts.

In principle, directional couplers can be constructed using coaxial technology, on the basis of strip line (Fig.2) or sandwich technology. CAE and CAD software are usually used for dimensioning nowadays.

2. CABLE COUPLER

The so-called wireline, which is available by the metre or centimetre, and which makes it possible to manufacture couplers with largely freely selectable data, has gained a certain degree of acceptance. Unfortunately, this decidedly expensive material does not permit the tidy installation of plugs and sockets, but is designed for integrated circuit technology.

The most frequent application of this interesting component lies in 3dB couplers with two outputs in opposition of phase (Fig's.3 and 4).

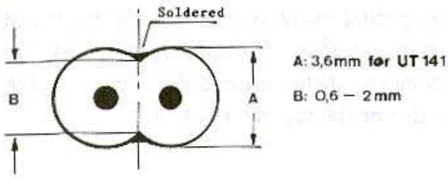


Fig.5: Structure of a Directional Coupler made from Fixed Sheath Cable

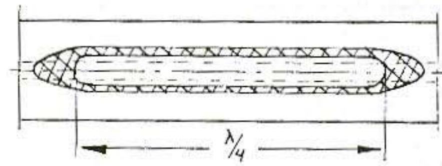


Fig.6: Filed longitudinal slit

A somewhat unconventional solution to the impedance problem lies in the use of additional longitudinally slit fixed cover cables as main and secondary lines. Here the manufacturers have already taken steps to ensure that the circuit is laid out in accordance with the impedance.

For a directional coupler made from individual semi-rigid circuits (Fig.5), the coupling area consists of a longitudinal slit (Fig.6) on the two circuit covers. The cable sections should first be bent at the planned lengths and then worked on with a smooth-cut file. To avoid "hillocks" on the worked surface, the straightness of the filing work should be checked repeatedly. Once matched to one another, the cable covers are longitudinally pre-tinplated, made smooth again, and then soldered (Fig's.7 and 8).

The wider these slits are, the stronger the coupling is. In addition to the width, the length of the openings contributes to the strength of the coupling (Fig.9). If the lengthwise dimension of the coupling area amounts to a quarter of the wavelength,

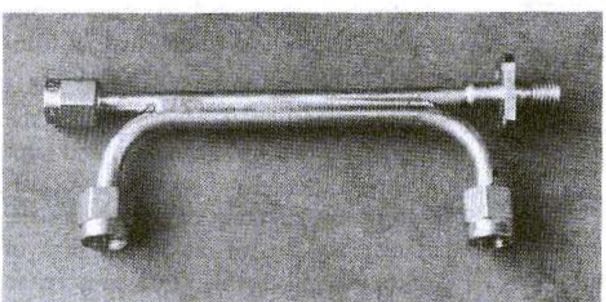


Fig.7: Ready-made Directional Coupler made from slitted and soldered Fixed Sheath cables

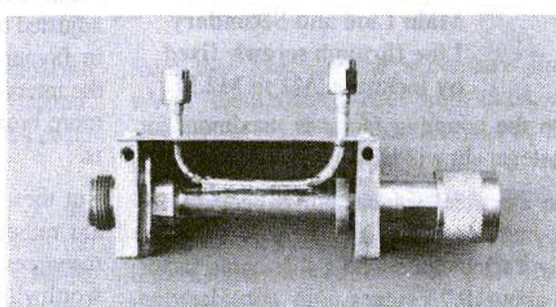


Fig.8: High-Power version from DK1VC

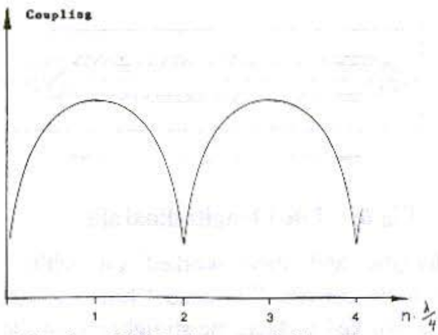


Fig.9: Main Curve of Coupling between Main Line and secondary Line, plotted against Length of Coupling Distance

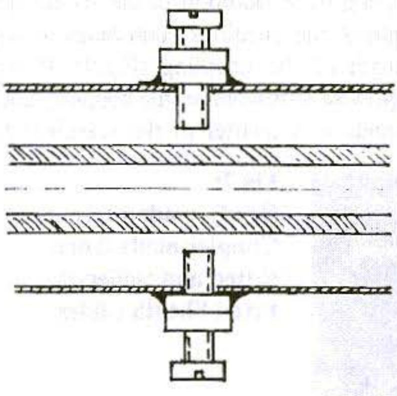


Fig.10: Transverse section of Capacitive compensation on Main Line and Secondary Line through screws fixed by locknuts (M2 to M2.5)

then the coupling factor is maximum for whatever slit width has been selected.

The electrical wavelength is decisive for the individual type of cable. In practice, only Teflon cable with a shortening factor of about 0.7. comes into consideration here. For an effective wavelength of lambda/2 or its whole-number multiples, the partial currents cancel each other out again, so that, theoretically at least, no inductive disturbance exists between the main and the secondary lines.

2.1. Compensation for faults

Wide coupling slits are required for the strong coupling which is frequently desired. Because of the impedance interference in the coaxial system, which can then no longer be ignored, the internal reflection on the measuring lines increases. The line impedance no longer coincides with the impedance of the other line sections or with that of the covers, which has an adverse effect on the accuracy of alignment. As long as the coupling distance is short by comparison with the wavelength, the capacitive electric stress for the internal conductor, which is too low as a result of the incomplete cable cover, can be selectively compensated. In practice, one or more screws can be attached as trimmers (Fig.10).

The compensation is carried out at the optimum accuracy of alignment, and happily it is a broad-band operation. Adjustments of this kind may offend the purists, but they are carried out in the best of circles, even in the high-frequency range itself. The accuracy of alignment can be adjusted to values which can exceed 40dB in favourable circumstances. The shorter the intervals between the trimmers are, the more broad-band the compensation effect is.

But these compensating measures, which are rather costly in terms of mechanical resources, could be considered as being worthwhile only if high accuracy of alignment is really of importance.

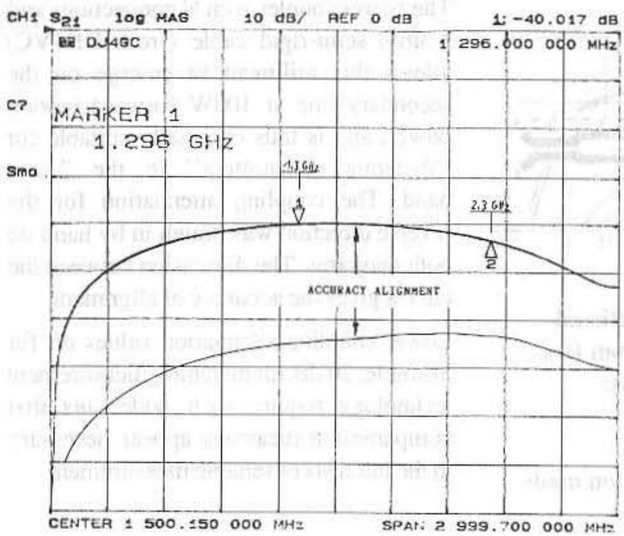


Fig.11: Functional Plot of the UT141 Coupler from Fig.7

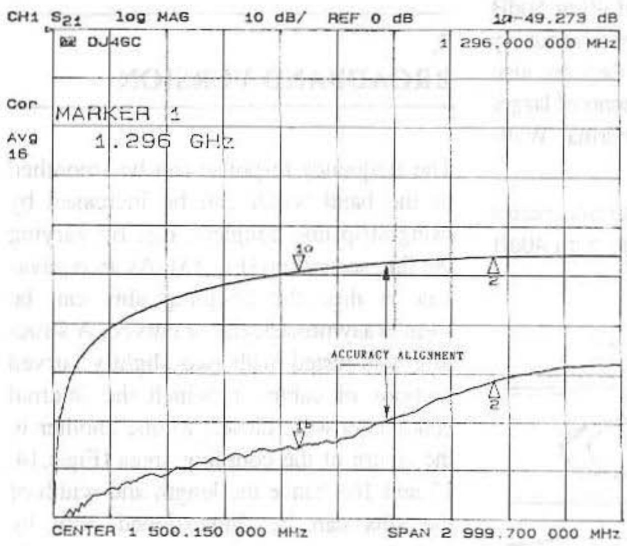


Fig.12: Functional Plot of the High-Power Coupler shown in Fig.8

No compensation is required to measure the forward motion power of a transmitter, because the faults are of a very small order of magnitude.

During compensation, the SWR of the main line is initially optimised, with the help of as good a standard joint as possible. In the second stage, the signal return loss from this joint on the secondary line, which theoretically does not exist, is adjusted in practice, with the help of the adjusting screws positioned there, to values as low as possible, or ideally to zero.

The frequency responses recorded for two uncompensated couplers by SSB-Electronic (tnx) are shown Fig's.11 and 12 and

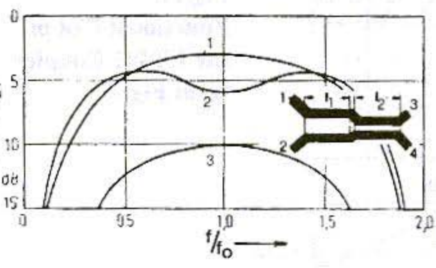


Fig.13: Broadband Directional Coupler made from two Coupling Sections:
1) 3dB Coupler
2) 10dB Coupler
3) Series connection made from 1) and 3)

show coupling attenuations of 40 or 50dB in the 23-cm. band. In addition to accuracy of alignment measurements, they are also suitable for precise measurements of larger transmission circuits using thermal Watt-meters.

Thus 10W in a transmission circuit creates 1mW at the measurement gate with 40dB coupling attenuation.

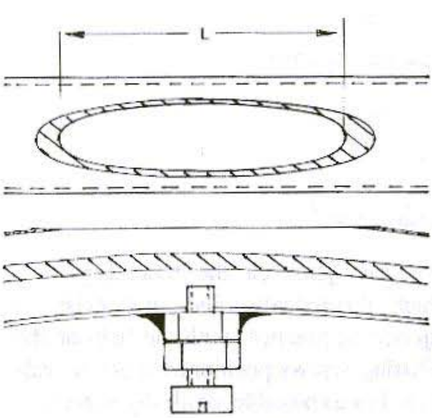


Fig.14: Two views of the filed coupling slit for the Broadband Coupler

The power coupler with N connections and 8.3mm semi-rigid cable (from DK1VC) allows this milliwatt to emerge on the secondary line at 100W forward motion power, and is thus especially suitable for "dynamic transmitters" in the 23cm. band. The coupling attenuation for the reverse direction was drawn in by hand on both diagrams. The dimension between the curves gives the accuracy of alignment.

Lower coupling attenuation values of, for example, 20 dB for matching measurement technology require such wide slits that compensation measures appear necessary in the interests of reliable measurement.

3. BROADBAND VERSION

The frequency response can be smoothed or the band width can be increased by using strip line couplers, e.g: by varying the line separation (Fig.13). As an equivalent to this, the coupling slits can be formed asymmetrically or curved. A structure was tested with two slightly curved sections of cable, in which the internal conductors were closest to one another in the centre of the coupling areas (Fig,s.14, 15 and 16). Since the length and width of the slits can be dimensioned only by high-frequency experience and guesswork, and not by means of software, the values provided give only approximations on the way to even broader band widths.

The readings (Fig.17) show that this solution can be applied over a range of approximately 1 to 4 GHz. However, it would seem that lengthening the coupling slit from 23mm to approximately 27mm

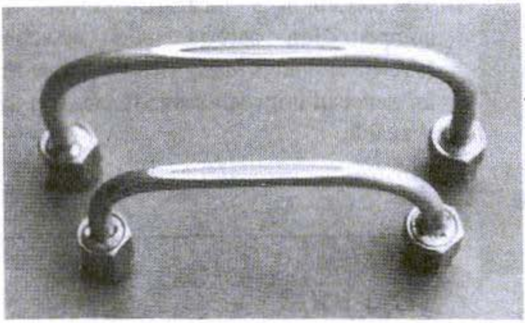
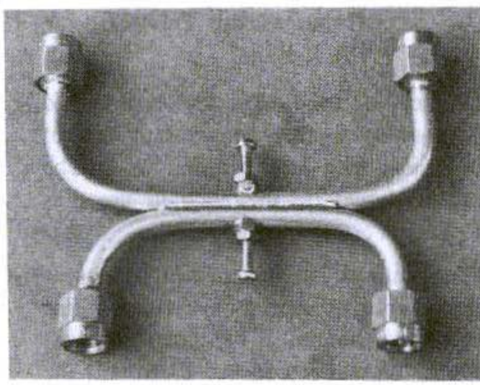


Fig.15:
Prepared Cable sections for Broadband Coupler

Slit length: 23mm
Max slit width: approx. 2mm

Fig.16:
Ready-made Directional Coupler with Screw Trimmers



would tend to make the drop at 1.3 GHz less pronounced. Because of the strong coupling, compensation of the capacitive electric stress for the internal conductor, which is too low, is required in the interests of high accuracy of alignment.

Accuracy of alignment values of over 40dB can be adjusted for, even with only one M2 screw as a trimmer in each case, though this was sacrificed once again in favour of broader band widths (three amateur radio bands). If several screw

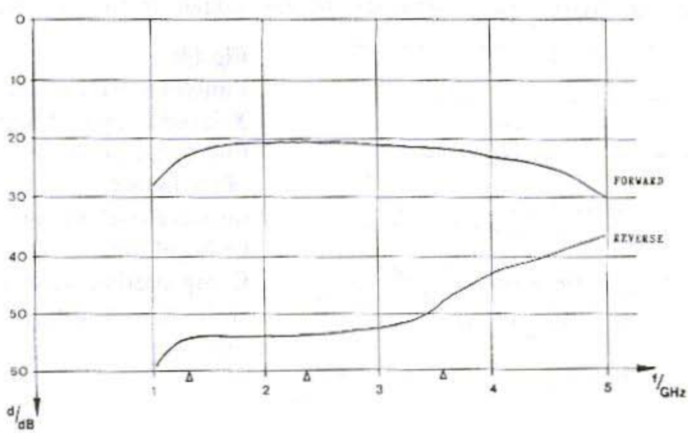


Fig.17:
Functional Plot of the Broadband Coupler from Fig.16

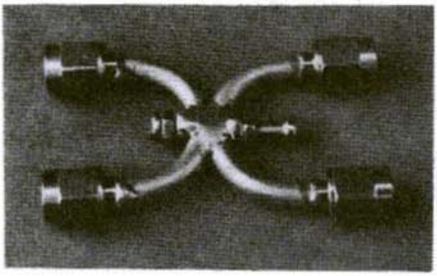


Fig.18: Directional Coupler with Compensation Trimmers for the X-Band

trimmers are used on each side, it should be possible to increase the accuracy of alignment with even broader bands. The values shown on the diagram are thus dependent on compensation.

The accuracy of alignment at high frequencies can be increased at the expense of that at low frequencies. If the gates are transposed, the readings remain essentially the same.

Even for the X-band, the technique seems very efficient. With a coupling slit length of 6mm (Fig.18), the range between 8 and 12 GHz can be covered and, at least over the range which is interesting for amateur radio, an astonishing accuracy of alignment of 30dB can be adjusted for (Fig.19).

The return loss measured before the compensation screws were attached (shown in dotted lines) clearly shows the influence of impedance interference on the slit cable.

4. TEST RIGS

The optimising and calibrating of the aforementioned directional couplers imposes certain requirements on measurement technology. For use within one band only, it is, of course, possible to carry out a test or a compensation, using a transmitter and a simple detector or receiver.

Network analysers provide an extremely convenient system for broad-band measurements, even if they are also complicated and difficult to obtain. Two "hard copies" produced in this way are reproduced here.

An electrical rig giving almost equivalent values using modular 50 ohm components should be referred to here (Fig.20). It makes it possible to measure the broad-band coupler and the X-band coupler. The accuracy of the output meter has no

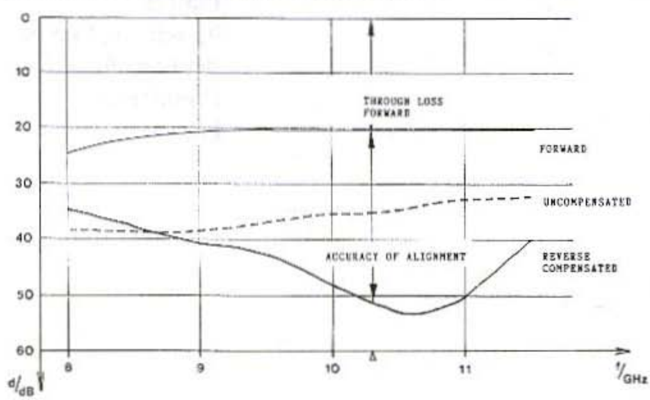


Fig.19: Functional Plot of the X-Band Coupler from Fig.18; the accuracy of alignment measured before the fitting of the Compensation Screws is shown as a dotted line

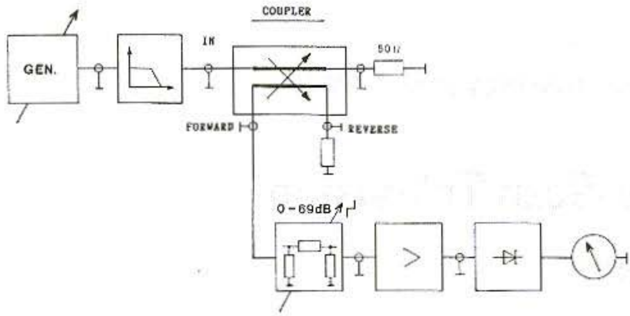


Fig.20: Basic set-up of measuring Equipment for determining Forward Attenuation (Through-Loss) and Return Loss

influence on the result, since it should merely always recognise the same level. The detector or thermal output meter must, if necessary, maintain a limiting sensitivity of approximately -50dBm, by means of broad-band preamplifiers.

The low pass filters after the generators are of great assistance in measuring high accuracy of alignment, since otherwise errors could be introduced due to harmonics. The quality of the 50 ohm joints, the coaxial transitions and the fact that the capacitive electric stress for the internal conductors can be balanced by screw trimmers only to a limited extent, set limits on the road to couplers which are always accurately aligned.

The goal could be considered as having been achieved if a return loss of more than 30dB could be obtained with quite a broad band.

The author hopes to have been of some assistance, and provided some ideas on how you can make these high-frequency components yourself, as they are scarcely obtainable otherwise.

5. LITERATURE

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